

Motivation and Objectives

- Dust emission is complex process that depends on the wind stress and land-surface condition.
- While global dust models have improved notably over the last decade, they still face numerous challenges.
- Deficits of state-of-the-art global dust models** include (Fig. 1):
 - an incomplete representation of the physics of dust emission
 - a lack of skill to reproduce certain atmospheric processes that drive dust emission
 - a poor representation of small-scale dust sources, in particular those related to anthropogenic land-use change

We aim to

- Redress model deficits related to the **dust emission mechanism and meteorological dust injection processes**
- Reduce uncertainty in modelled dust emission along with **attribution to natural and anthropogenic origin**

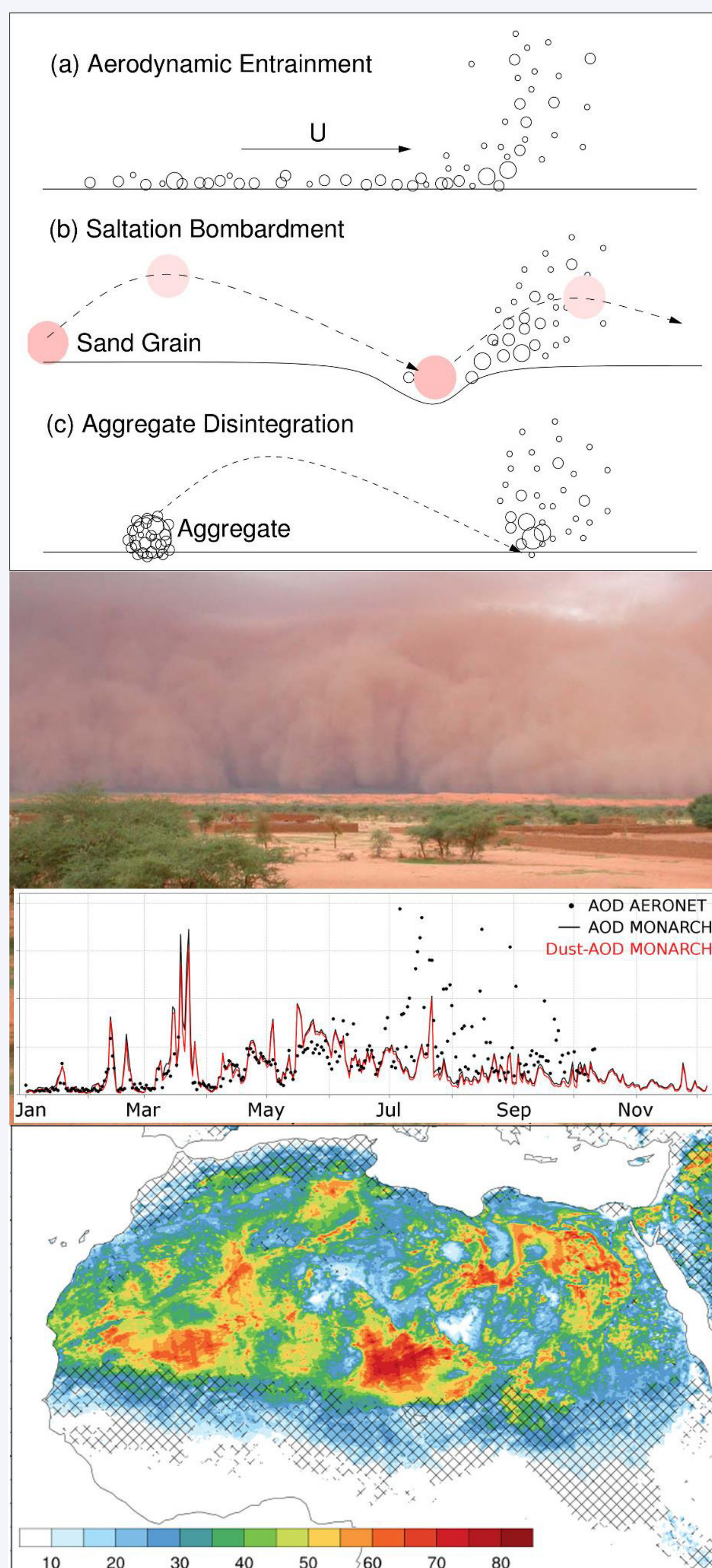


Fig. 1: (a) Mechanisms of dust emission (from Shao, 2008); (b) Leading edge of a haboob (from Knippertz and Todd, 2012) and comparison between modelled (MONARCH – total: black line; dust contribution: red line) and measured (AERONET – black dots) aerosol optical depth (AOD) at Tamanrasset, Algeria, during 2015. Summertime moist-convective dust storms lead to substantial model-observation discrepancies in current models; (c) Frequency of Occurrence (FoO) that AOD exceeds a threshold of 0.2 for natural and anthropogenic (dash pattern) dust sources in northern Africa.

Uncertainty: Physics of dust emission

- The three main mechanisms of dust emission are aerodynamic entrainment (AE), saltation bombardment (SB), and aggregate disintegration (AD)
- Dust emission schemes used in regional and global models usually represent SB only or SB and AD.
- AE is normally neglected, because emissions produced by AE are much smaller than by SB/AD. However, recent studies suggest that AE can be significant (e.g. Klose et al., 2014; Fig. 2)

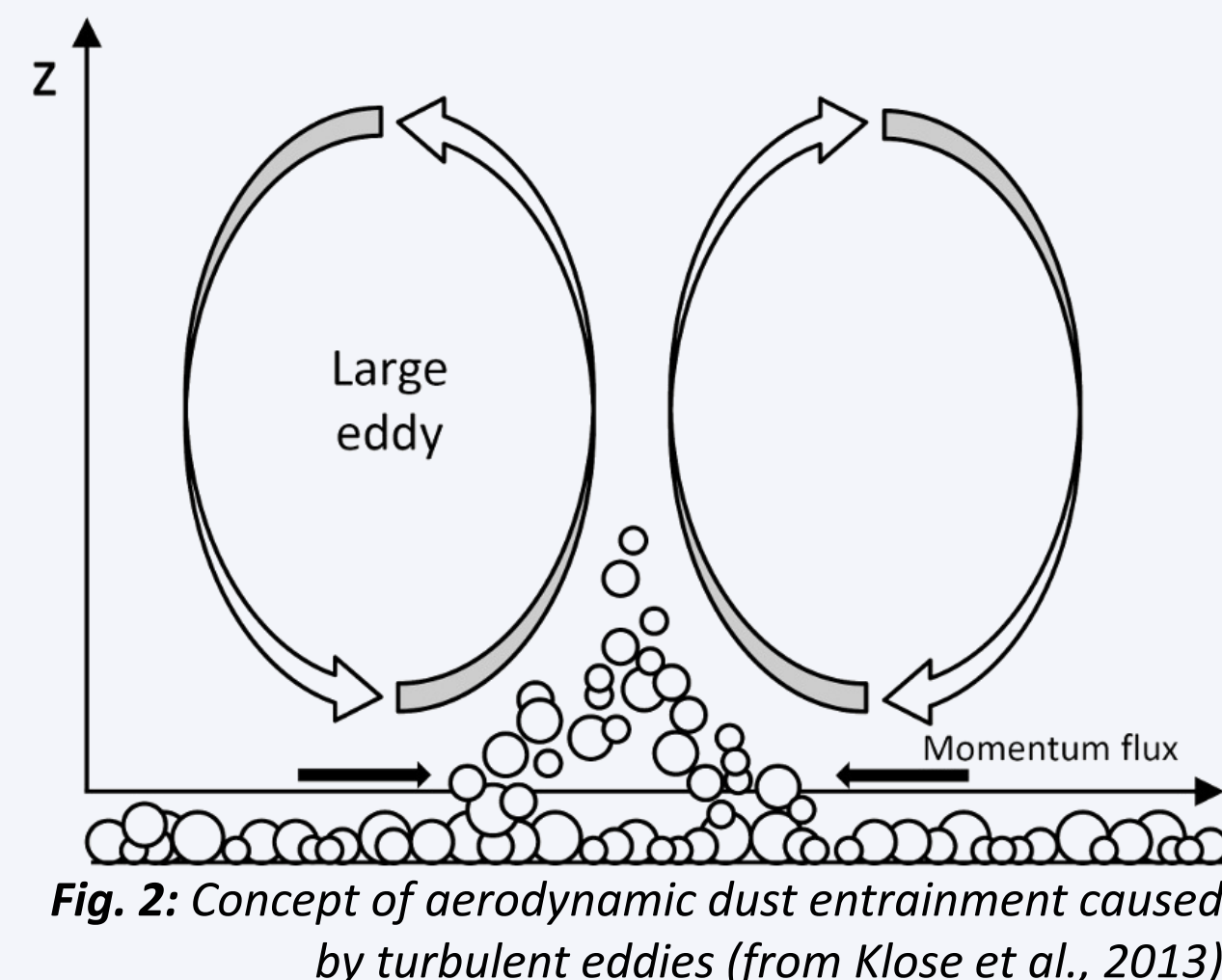


Fig. 2: Concept of aerodynamic dust entrainment caused by turbulent eddies (from Klose et al., 2013)

- The **long-term global significance of aerodynamic dust emission** compared to saltation-generated dust emission and the **associated environmental effects** are unknown.

- We will use and further develop the parameterization of Klose et al. (2014) to determine aerodynamic entrainment and its effects globally.

Uncertainty: Meteorological dust injection processes

- Mesoscale convective dust storms (MCS) or ‘haboobs’ are among the most important meteorological dust injection processes in the Sahara in summer, both in terms of cumulative duration and intensity (Allen et al., 2015)
- Modeling of MCS remains a challenge, in particular for coarse-grid global models.
- Only few attempts have been made to parameterize MCS in a way that could in principle be used in large-scale models (Miller et al., 2008; Pantillon et al., 2016; Fig. 3)
- The **inclusion of moist-convective dust storms** in global models could significantly **improve estimates of the amount, spatial distribution, and seasonal and interannual variability** of global dust emission.

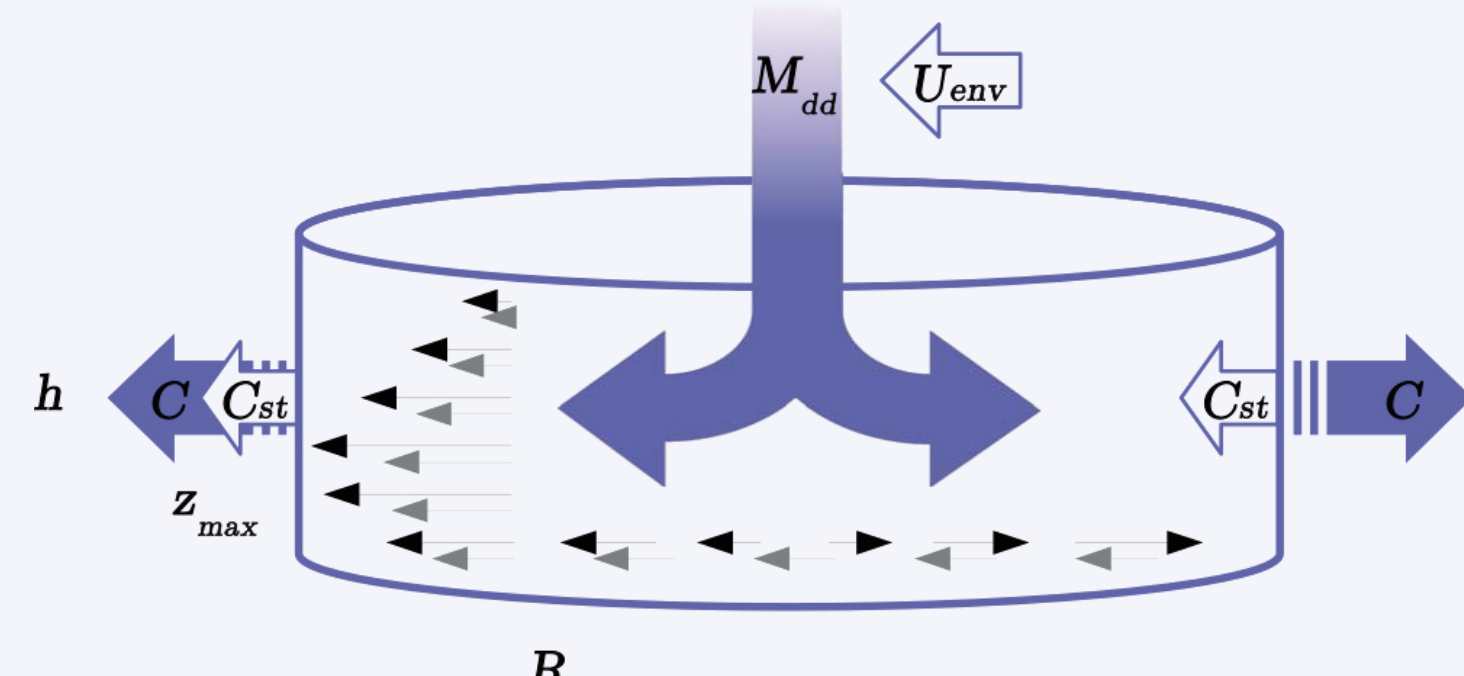


Fig. 3: Concept of dust entrainment through downdrafts from moist convection (from Pantillon et al., 2016)

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Uncertainty: Natural and anthropogenic dust sources

- Major dust sources are preferentially located in topographic depressions where a deep layer of alluvium has accumulated, but they can also be generated by human activities, such as agriculture, that disturb the soil and make it vulnerable to wind erosion.
- The contribution of (anthropogenic) land use to present-day dust emission remains under debate, with values ranging from 10% to 50% (Tegen et al., 1996; Tegen et al., 2004; Mahowald et al., 2004; Ginoux et al., 2012)
- This uncertainty is partly caused by the poorly constrained wind friction velocity threshold for particle lifting, u_{*t} , which depends on soil texture, soil moisture, and surface roughness. Most global dust models assume a spatially uniform dry threshold with variations depending only on soil moisture, omitting the influence of vegetation and other environmental factors.
- To better estimate the contribution of agricultural (cultivated) and natural sources to global dust emission, **improved land-surface representations need to be combined with advanced dust models and observational constraints**.

Preliminary results – anthropogenic fraction

Numerical Experiments

- Multiscale Online Non-hydrostatic Atmosphere Chemistry model – NMMB-MONARCH (Pérez et al., 2011; Badia et al., 2017)
- Global setup ($1^\circ \times 1.4^\circ$ horizontal resolution, 24 layers)
- Initially one-year simulations

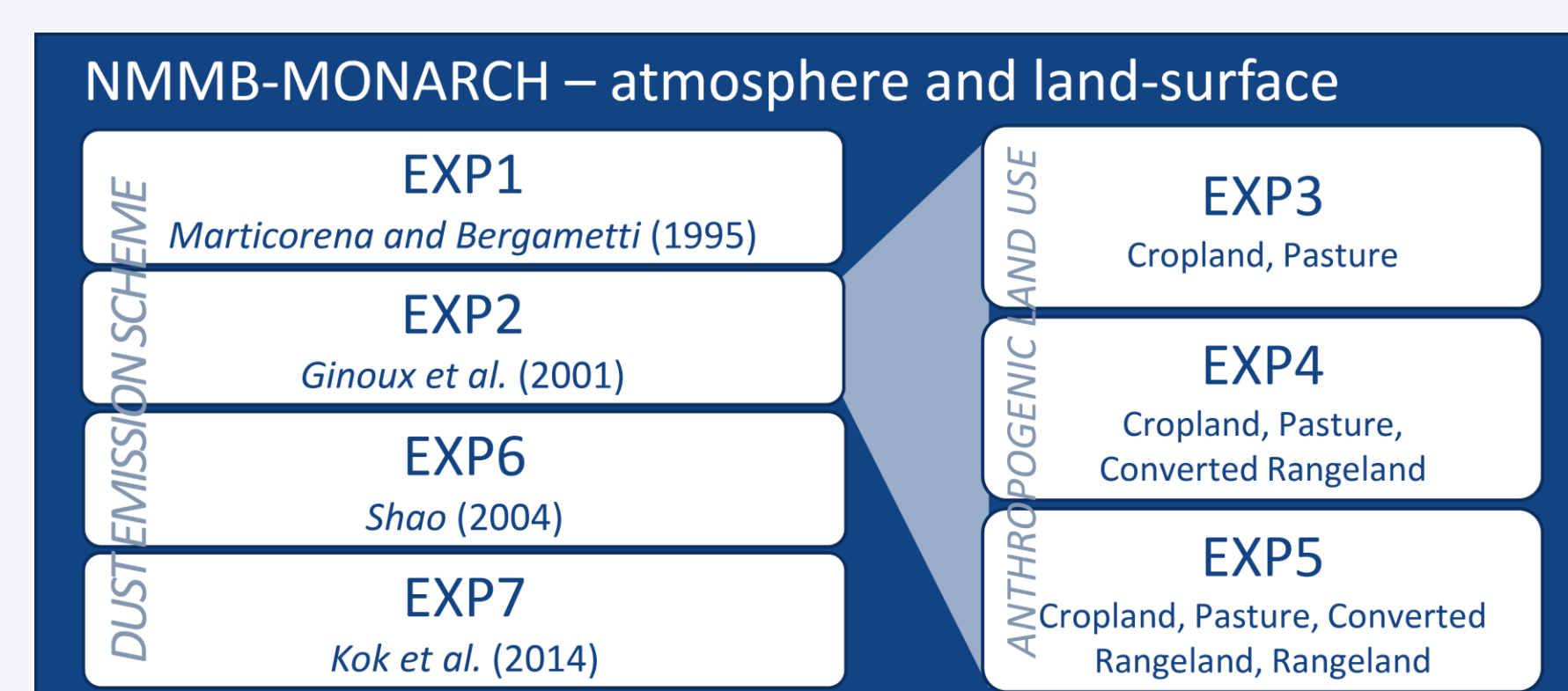
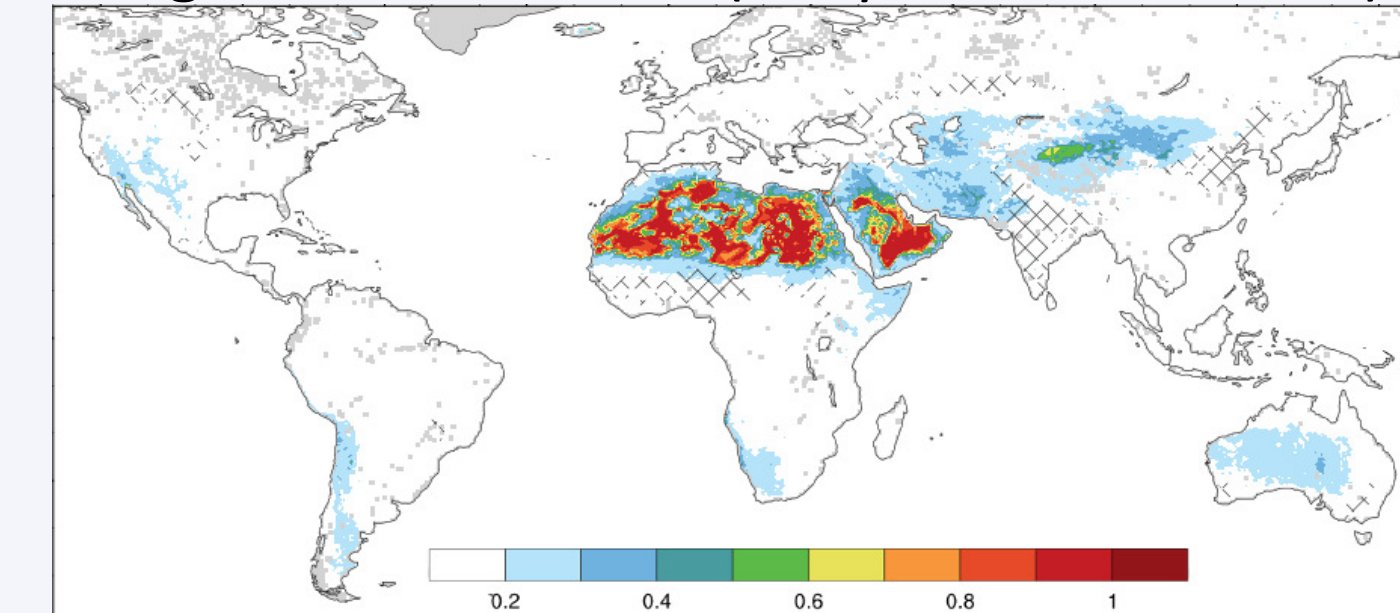


Fig. 4: Overview of the numerical experiments designed to constrain the contribution of anthropogenic sources to the global dust cycle.

Drag Partitioning

- “Drag partition” describes the separation of the total (surface) drag supplied by aerodynamic forces into a fraction on roughness element surfaces and on the ground surface. The latter is pivotal for dust emission.
- In the context of dust emission modeling, drag partition is usually used to account for roughness elements, such as vegetation, in the sediment entrainment threshold.
- We use the drag partition parameterization of Raupach et al. (1993) in combination with estimates of photosynthetic (PV) and non-photosynthetic (NPV) vegetation cover (Guerschman et al., 2015) and the conversion between cover fraction and frontal area index (input to the drag partition scheme) proposed by Shao et al. (1996).
- Fig. 5 compares the resulting roughness correction factor used to correct u_{*t} with the frequency of occurrence (FoO) of dust optical depth > 0.2 (Ginoux et al., 2012). The main features show remarkable similarity demonstrating that vegetation or roughness element cover is a key factor for dust emission and that a dynamical representation of u_{*t} is crucial to reproduce observed atmospheric dust loadings.

Roughness correction (Raupach et al., 1993)



FoO of DOD > 0.2 (Ginoux et al., 2012)

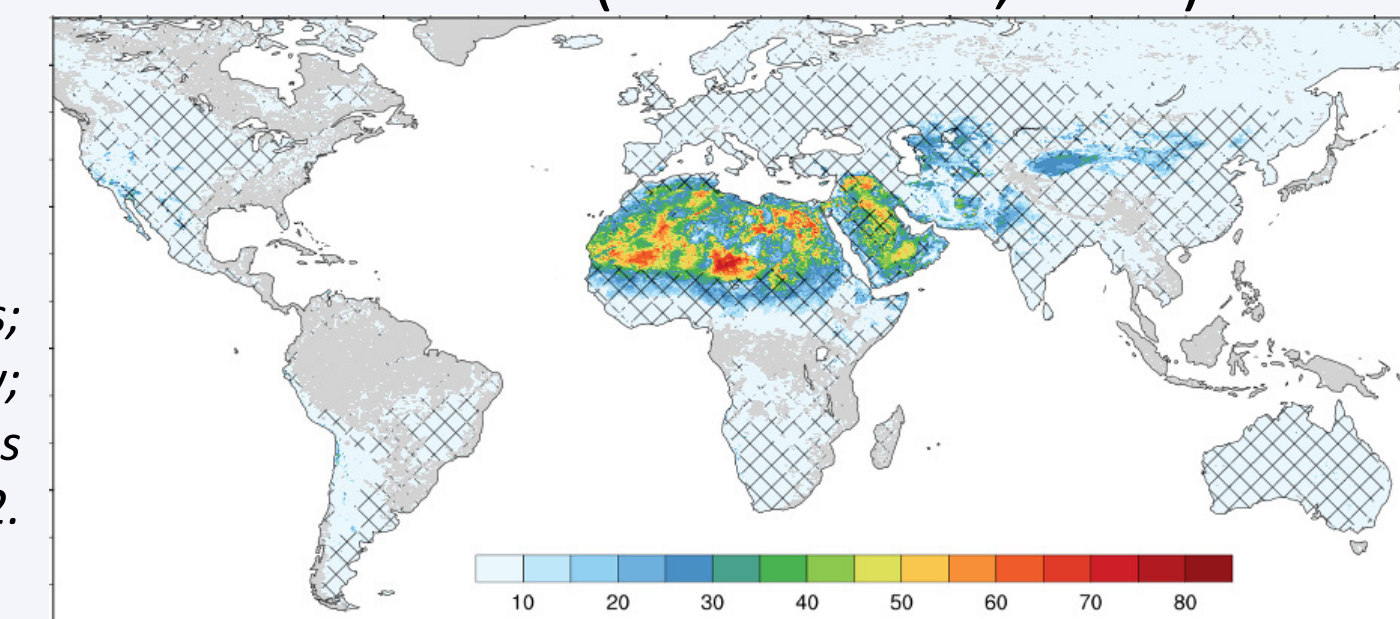


Fig. 5: (top) Correction factor representing roughness elements; the factor is applied to the entrainment threshold friction velocity; (bottom) Frequency of occurrence (FoO) of dust optical thickness (DOD) > 0.2.

Anthropogenic land use

- Ginoux et al. (2012) considered a dust source anthropogenic if it contained $> 30\%$ anthropogenic land use (cropland and pasture) based on HYDE 2.
- We use an updated land-use data set (HYDE 3.2.1) and test different scenarios of anthropogenic sources categories: (a) Cropland and pasture; (b) cropland, pasture, and converted rangeland; and (c) cropland, pasture, converted rangeland and rangeland.

Constraining the dust cycle with observations

- Model best-estimates** for each experiment are obtained by minimizing the error between model results and a suit of observations, e.g. MODIS or AERONET aerosol optical thickness
- The resulting optimization factor is applied to the modeled dust cycle globally; the spatio-temporal dust variation remains as independent quality criterion.
- Detailed evaluation of the spatial and temporal distribution of dust**, relative amount of dust load and deposition, etc. is currently underway and will allow to identify model weaknesses and test hypotheses on the anthropogenic fraction (Fig. 6).

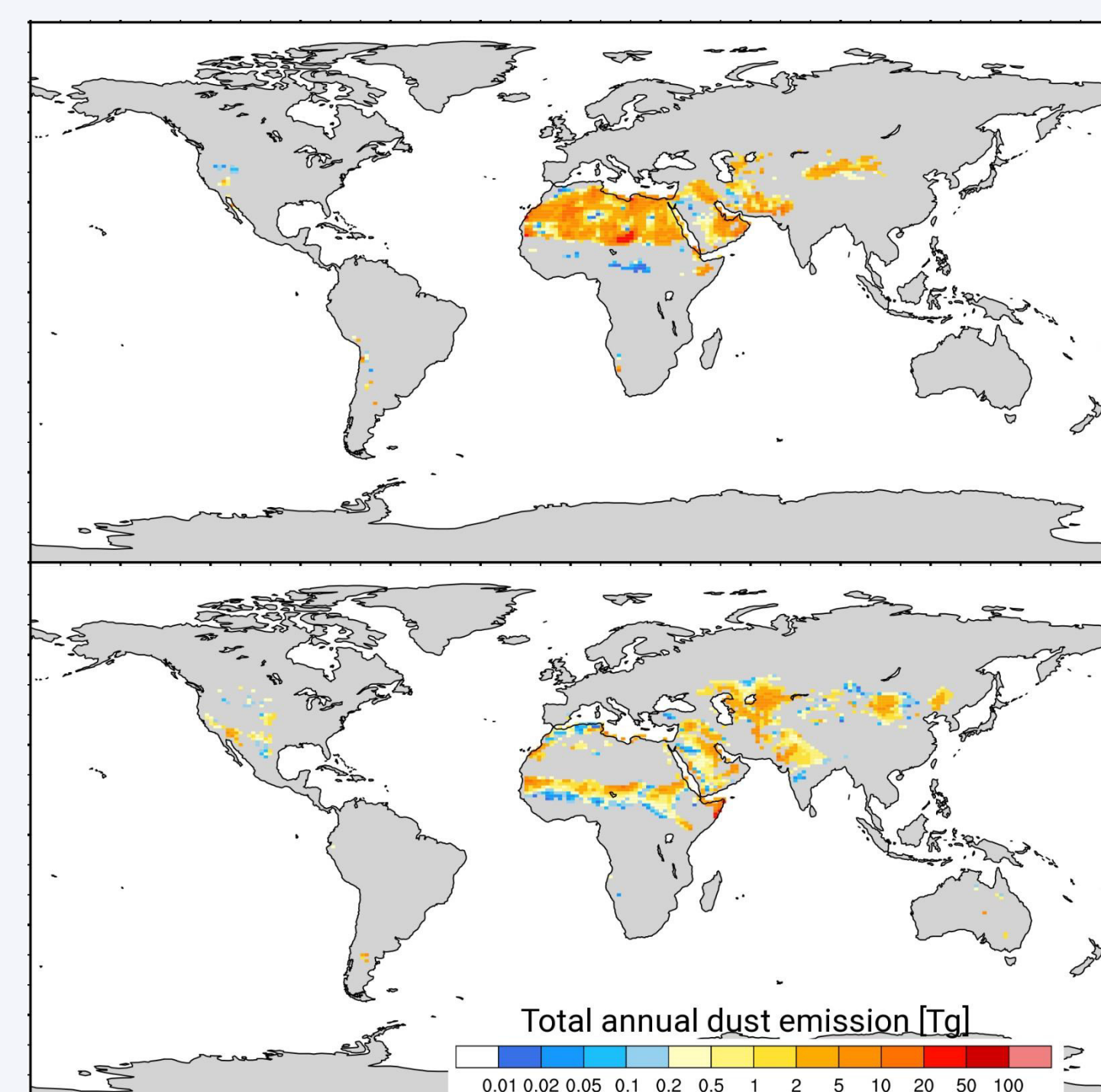


Fig. 6: Example of total annual dust emission [Tg] originating from natural (top) and anthropogenic (bottom) sources during the year of 2012.)



Acknowledgements This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 789630. We furthermore acknowledge support from the the AXA Research Fund.